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(54) **Ramp generators**

(57) A voltage-controlled ramp generator has a comparator (1) with two inputs to one of which is applied an input voltage Vi. A source of a control voltage Vr determines the ramp time constant of the generator. A clamp (5, 6) clamps the output of the comparator (1) to a voltage related to the control voltage and an integrator (2) has two inputs to one of which is applied the output of the comparator (1). Means (12) applies to the other input of the integrator (2) the voltage related to the control voltage Vr to determine the characteristics of the output from the integrator. The output of the integrator forming the ramp output, is applied to the other input of the comparator (1).

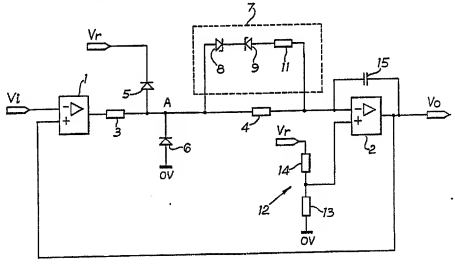

Fig.1

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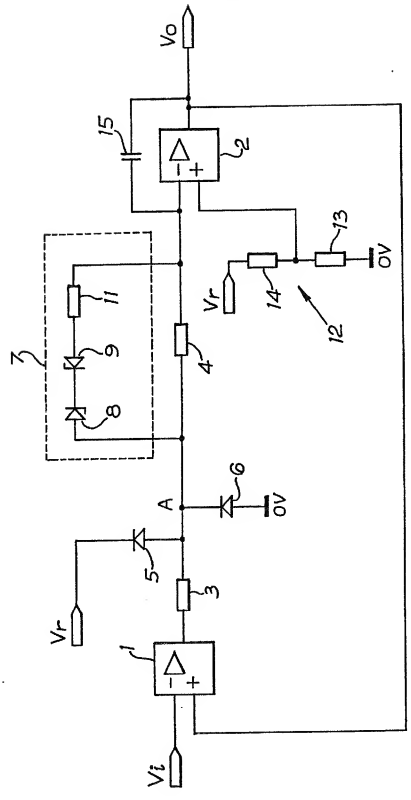
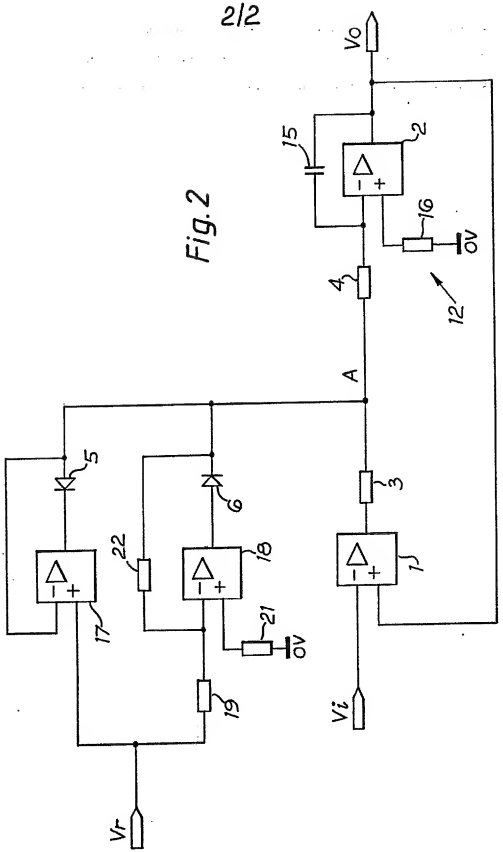


Fig.1

Fig. 2



RAMP GENERATORS

This invention relates to ramp generators and more particularly to such generators which are voltage controlled.

Ramp generators are well known per se but suffer from having a relatively high component count or compromising performance.

According to one aspect of the present invention there is provided a voltage-controlled ramp generator comprising comparator means having two inputs to one of which is applied an input voltage; a source of a control voltage operable to determine the ramp time constant of the generator; means for clamping the output of the comparator means to a voltage related to the control voltage; integrator means having two inputs to one of which is applied the output from the comparator means; and means for applying to the other input of the integrator means a voltage related to the control voltage to determine the characteristic of the output from the integrator means, and hence the output of the ramp generator, the output of the integrator means being applied to the other input of the comparator means.

The means for applying a voltage to the integrator means which is related to the control voltage may comprise resistive means to which the control voltage is also applied. Alternatively, the resistive means may provide a voltage to the integrator means which is related to, but not derived directly from, the control voltage.

The clamping means may comprise a matched pair of Zener diodes connected between the control voltage and ground. This arrangement is relatively simple but in order to extend the operating range and symmetry of the ramp generator, the diodes may be contained within an amplifying loop to which the control voltage is applied, whereby the effect of the voltage drops across the diodes are eliminated. The amplifying loop may comprise a non-inverting operational amplifier in parallel with an inverting operational amplifier, the diodes being connected in series with the respective outputs of the operational amplifiers.

The comparator means and the integrator means may also be in the form of operational amplifiers.

The clamping means is adjustable by the control voltage which is a useful feature per se and according to a second aspect of the invention there is provided a voltage-controlled ramp generator comprising comparator means having two inputs to one of which is applied an input voltage; a source of control voltage operable to determine the ramp time constant of the generator; integrator means having two inputs to one of which is applied the output from the comparator means, and means for clamping the output of the comparator, the clamping means being responsive to the control voltage and thus operable adjustably to clamp the output of the comparator means in accordance with the control voltage.

As with the first aspect of the invention, the clamping means may comprise a matched pair of diodes connected between the control voltage and ground or contained within an amplifying loop to which the control voltage is applied.

Voltage-controlled ramp generators in accordance with the present invention will now be described in greater detail, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a schematic circuit diagram of a first embodiment, and

Figure 2 is a schematic circuit diagram of a second embodiment.

With reference first to Figure 1 of the drawings, this illustrates a relatively simple and inexpensive ramp generator which is voltage-controlled and exhibits a good performance even though the component count is relatively low, hence the simplicity of the circuit. The ramp generator comprises comparator means in the form of an operational amplifier 1 to the negative (inverting) input of which there is connected an input voltage signal Vi. The output of the comparator 1 is applied to the negative input of integrator means which is also in the form of an operational amplifier 2, the output being applied via two series resistors 3 and 4. Between the resistors 3 and 4 there is connected a source of a control voltage Vr via a diode 5. A further diode 6 which is matched to diode 5 is also connected between a zero volt rail or line and the junction between the resistors 3 and 4. A circuit 7 may optionally be connected in parallel with the resistor 4 and comprises two reverse biased Zener diodes 8 and 9 and a resistor 11, these three components being connected

in series across the resistor 4. The circuit 7 may be used to extend the operating range of the ramp generator as will be further described herein after.

The ramp generator also comprises means indicated generally at 12 for applying to the positive (non-inverting) input of the integrator 2 a voltage which is related to the control voltage Vr, these means thus being operable to determine the characteristic of the ramp output signal of the generator and the output of the integrator 2, which output signal is designated Vo. The circuit means 12 comprise two series resistors 13 and 14 connected between the control voltage Vr and the zero volt line, the junction between the resistors 13 and 14 being connected to the positive input of the integrator 2. The integrator 2 has a capacitor 15 connected between the negative input and the output thereof, and the output of the integrator is fed back to the positive input of the comparator 1. The ramp generator of Figure 1 performs a ramp function, the duration of which is controlled inversely by the control voltage Vr. The output voltage Vo of the ramp generator always seeks to be equal to the input voltage Vi but if the Vi suddenly changes, then the output voltage Vo will ramp linearly towards Vi. The comparator 1 compares Vi with Vo and if Vo < Vi, then the comparator 1 will saturate negative,

diode 6 will be forward biased and the voltage at the junction between the resistors 3 and 4 will be -Vd, where Vd is the voltage drop across the forward biased diode 6. Hence, current will charge the capacitor 15 and the output voltage Vo will ramp upwards until Vo = Vi. At this point, the comparator 1 will no longer saturate but will maintain an error voltage sufficient to maintain Vo = Vi.

If Vo > Vi, then the comparator 1 will saturate positive, diode 5 will be forward biased and the voltage at the junction between the resistors 3 and 4 will be Vr + Vd. Hence, the capacitor 15 will be charged and Vo will run downward until Vo = Vi.

Ignoring circuit 7 and assuming resistors 13 and 14 to be equal and resistor 3 to be much less than resistor 4, then from the transfer function of an integrating operational amplifier there is derived:-

$$Vo = \frac{-1}{C1} \int i dt$$

Where i is the current through C1 and C1 = capacitor 15.

$$Vo = \frac{-1}{C1\ R2} \int_{Vi\ step}^{Vo = Vi} (Va - Vr/2)dt$$

Where R2 = resistor 4.

If Va remains constant, then at time t after a sudden Vi change occurs:

$$Vo = \frac{-(Va - Vr/2)t}{C1\ R2}$$

Therefore

$$t = \frac{-\ C1\ R2\ Vo}{Va - Vr/2}$$

Define ramp time T as the ramp time taken for a step input Vs at Vi.

Therefore make Vo - Vs.

$$T = \frac{-\ C1\ R2\ Vs}{Va - Vr/2}$$

For ramping upwards, then Va = - Vd2

$$Tup = \frac{+\ C1\ R2\ Vs}{(Vd2 + Vr/2)}$$

For ramping downwards, Va = Vr + Vdi

$$T\ down = -\ \frac{C1\ R2\ Vs}{(Vdi + Vr/2)}$$

It will be appreciated that the embodiment of Figure 1 of the drawings is relatively simple, having a low component count, but the ramp slope is voltage-controlled, thus providing a very useful facility. Most adjustable ramp generators are only potentiometer controlled but with the embodiment of Figure 1 of the drawings, the ramp time may be defined either by an applied voltage or by a potentiometer. The circuit is

considerably simpler and less expensive than known voltage-controlled ramp generators and is as simple as other inferiorly performing potentiometer adjustable linear ramp generators.

Very accurate up and down ramp slop symmetry is achieved as a result of the resistive division of the control voltage Vr at the positive input of the integrator 2. The only significant causes of assymetry are the matching of the resistors 13 and 14 and the matching of the forward voltage drops of the diodes 5 and 6. Readily available and 1% tolerance resistors can be chosen for resistors 13 and 14, making matching adequate for most applications. Matching of the voltage drops across the diodes 5 and 6 is more difficult to achieve in practice and specially matched diodes may have to be used in certain applications.

The forward biased voltage drop Vd is slightly current dependent and will be affected by the control voltage Vr. However, the Vr dependance will distort the slope symmetry more at higher values of Vr (shorter ramp times) because currents of different magnitudes will flow through the diodes 5 and 6. When Vr is zero volts, or very small, particularly with $V^+ = -V^-$ (V^+ and V^- being the power rails) the current through the diodes 5 and 6

will be approximately equal and the Vr dependence of Vd becomes insignificant at long ramp times. Hence, it is an important feature of the present invention that, unlike existing designs of ramp generator, the present generator is most symmetrical at longer ramp times, whereas in other linear designs symmetry is poor at long ramp times.

The ramp time adjustment range, is to some extent limited in the embodiment of Figure 1 of the drawings, this being due to the relatively limited adjustment range of the voltage Va which appears at the junction between the resistors 3 and 4. In this case, Va is a limiting factor and the range can be maximised by selecting the values of the diodes 5 and 6 with low Vd. Selecting an appropriate operational amplifier for the comparator 1 which saturates close to the power rails of the generator also assists. In order to improve the adjustment range, circuit 7 can be introduced as already briefly mentioned above. With the circuit 7 employed, if Vr is small, then diodes 8 and 9 are non-conducting and only resistor 4 defines the current through the capacitor 15 across the integrator 2. As Vr becomes sufficient to turn on one of the diodes 8 and 9 (which are preferably Zener diodes), then resistor 11 in the circuit 7 also defines the current through the capacitor 15.

The ramp time T is inversely proportional to Vr, whereby, as is the case with all basic linear ramp generator circuits, the adjustment of T is coarse for long ramp times and fine for short ramp times. For practical purposes, finer control is often desired for long ramp times and circuit 7 can be incorporated to this end. Careful selection of the diodes 8 and 9 and resistor 11 can also help compensate for this limitation.

The values of resistors 3, 4 and 11 must be chosen such that during ramping, Va is always defined by the action of either of the diodes 5 and 6 turning on. Va under these circumstances must not be defined by the potential dividing action of resistor 3 with resistor 4 (or resistor 11). Hence, resistor 3 should be much lower than resistor 4 (or resistor 11). Consideration must be given to the ratio of the resistor 3 and the Vr source impedance and a buffer amplifier may be employed in order to derive Vr.

If asymmetrical ramp times are required, then resistors 13 and 14 may be varied accordingly. Alternatively, the differential may be voltage controlled by independently varying the voltage on the positive input of the integrator 2.

Turning now to Figure 2 of the drawings, this illustrates an alternative embodiment with a higher performance than that of the embodiment of Figure 1 in as much as the range of operation is considerably extended and symmetry improved. As with the Figure 1 embodiment, the alternative embodiment comprises a comparator 1 in the form of an operational amplifier and an integrator 2 also in the form of an operational amplifier and having a capacitor 15 connected between its negative input and its output. Resistors R3 and R4 are also employed as before, being connected in series between the output of the comparator 1 and the input of the integrator 2.

The two principle differences between the embodiment of Figure 1 and 2 are firstly that the resistors 13 and 14 are dispensed with, whereby the circuit 12 for applying to the positive input of the integrator 2 a voltage related to the control voltage Vr comprises a single source resistor 16 connected to the zero volt line of the generator. The second difference is that the diodes 5 and 6 of the embodiment of Figure 1 are now incorporated, in the embodiment of Figure 2 in an amplifying loop to which the control voltage Vr is applied. The output of the loop being applied to the junction between the resistors 3 and 4. The amplifying loop comprises a non-inverting operational amplifier 17 to the positive input

of which the control voltage Vr is applied, with the negative input being connected to the output at a point beyond the series connection of the diode 5 in the output of the amplifier 17. The loop further comprises an inverting operational amplifier 18 to the negative input of which is applied the control voltage Vr via a resistor 19. The positive input of the operational amplifier 18 is connected to the zero volt line either direct or via a source resistor 21. The negative input of the operational amplifier 18 is also connected, via a resistor 22, to the output of the amplifier at a point beyond the series connection in the output of the diode 6.

With the incorporation of the diodes 5 and 6 into the feedback loop of the operational amplifier 17 and 18, whereby the effect of voltage Vd is eliminated. This overcomes the problems associated with the matching of the voltage drops across the respective diodes 5 and 6 and the Vr dependence on Vd. This also improves the available voltage range at the junction between the resistors 3 and 4 which can be reduced to zero volts. Accordingly, infinite ramp times are theoretically possible. The inverting operational amplifier 18 replaces the zero volts fed through the diode 6 in the Figure 1 embodiment and the voltage at the junction

between the resistors 3 and 4 is symmetrical about zero volts instead of about Vr/2 as in the embodiment of Figure 1. This further improves the ramp time range and in view of the overall extension of the range of the embodiment of Figure 2 of the drawings, then it is not necessary to incorporate in this embodiment circuit 7 of the embodiment of Figure 1.

It will be seen that in the alternative embodiment of Figure 2 of the drawings, asymmetry introduced by diodes 5 and 6 in the Figure 1 emboidment is here eliminated and the Vr input impedance is no longer a problem although resistors 3 and 4 must still be chosen, as in the first embodiment, such that during ramping Va is always defined by the action of either of the diodes 5 and 6 turning on.

By definition, the transfer function of an integrating operational amplifier is given by the following:-

$$Vo = \frac{-1}{C1} \int idt$$

Where i is the current through C1 and C1 = capacitor 15.

Hence

$$Vo = -\frac{1}{C1\ R2} \int_{Vi\ step}^{Vo = Vi} Va\ dt$$

Where R2 = resistor 4, and Va is the voltage at A.

If Va remains constant, then at time t after a sudden Vi change occurs,

$$Vo = \frac{-Vat}{C1\ R2}$$

$$t = \frac{-\ Vo\ C1R2}{Va}$$

Define the ramp time T as the ramp time taken for a step input Vs at Vi.

Therefore make Vo = Vs.

$$T = \frac{-\ C1R2Vs}{Va}$$

For ramping upwards, Va = - Vr

$$T\ up = +\ \frac{C1\ R2\ Vs}{Vr}$$

For ramping downwards, Va = + Vr

$$T\ down = -\ \frac{C1\ R2\ Vs}{Vr}$$

The embodiment of Figure 2 of the drawings basically has the same advantages as discussed above in relation to the Figure 1 embodiment and even though it has a higher component count, it is still simpler, and hence less expensive, than existing voltage controlled ramp generators with a similar performance. Extremely accurate symmetry on the up and down ramp times is obtained and the advantage of the first embodiment at long ramp times is combined with a much improved symmetry

at short ramp times. Symmetry at short ramp times is outstanding because the effect of the Vd dependence on Vr is eliminated. The ramp time range is almost unlimited with the embodiment of Figure 2 of the drawings. The limitation on the ramp range adjustment being coarse on long ramp times is similar to that discussed above in relation to the first embodiment. One possibility for compensating for this limitation without compromising performance is to modify the control Vr with a non-linearising amplifier before it is applied to the generator. The Vr input impedance is high but is affected by the resistor 19. If different up and down ramp times are required, then the voltage on the positive input of the integrator 2 or the operational amplifier 18 may be varied. Alternatively, the input to the operational amplifier 18 via the resistor 19 may be varied independently of the control voltage Vr.

The operating range of this second embodiment is greatly increased over that of the first embodiment because, as already mentioned, the effect of the voltage drops across the diodes 5 and 6 are eliminated. At the same time this gives Vr/2 as zero volts so zero volts can be applied to the integrator 2, thus making it possible to apply thereto a voltage which is related to, but not derived from, the control voltage Vr. If the voltage

applied to the positive input of the integrator 2 is other than 0 volts then the mid point of the voltage at point A in Figure 2 needs to be adjusted accordingly.

It will be appreciated from the foregoing that the present invention affords a voltage-controlled ramp generator which is relatively simple in construction and yet exhibits a high performance compared with known ramp generators. As regards the aspect of the variable clamping means, this affords a ramp generator in which the output of the comparator can be clamped to a different voltage without the need to change any components.

CLAIMS

1. A voltage-controlled ramp generator comprising comparator means having two inputs to one of which is applied an input voltage; a source of a control voltage operable to determine the ramp time constant of the generator; means for clamping the output of the comparator means to a voltage related to the control voltage; integrator means having two inputs to one of which is applied the output of the comparator means; and means for applying to the other input of the integrator means a voltage related to the control voltage to determine the characteristics of the output from the integrator means, and hence the output of the ramp generator, the output of the integrator means being applied to the other input of the comparator means.

2. A ramp generator according to claim 1, wherein the means for applying a voltage to the integrator means which is related to the control voltage comprises resistive means.

3. A ramp generator according to claim 2, wherein the resistive means comprises a resistive chain connected in series between the control voltage and zero volts, said other input of the integrator means being connected to a junction intermediate ends of the chain.

4. A ramp generator according to any of the preceding claims, wherein said other input of the integrator means is connected to zero volts.

5. A ramp generator according to any of the preceding claims, wherein the clamping means comprises a matched pair of diodes connected between the source of the control voltage and zero voltage.

6. A ramp generator according to claim 5, wherein the diodes are incorporated into an amplifying loop connected between the source of the control voltage and the integrator means.

7. A ramp generator according to claim 6, wherein the amplifying loop comprises a non-inverting amplifier connected in parallel with an inverting amplifier, with the diodes being incorporated into the respective output lines of the amplifiers within feedback loops thereof.

8. A ramp generator according to any of the preceding claims, and further comprising circuit means operable to extend the operational range of the generator, the circuit being arranged to shunt an input resistor connected to said one input of the integrator means.

9. A ramp generator according to claim 8, wherein said circuit comprises a pair of reverse biased diodes in series with a resistor.

10. A ramp generator according to any of the preceding claims, wherein the comparator means and integrator means are each in the form of an operational amplifier.

11. A ramp generator substantially as herein particularly described with reference to Figure 1 or Figure 2 of the accompanying drawings.

12. A voltage-controlled ramp generator comparator means having two inputs to one of which is applied an input voltage; a source of control voltage operable to determine the ramp time constant of the generator; integrator means having two inputs to one of which is applied the output from the comparator means, and means for clamping the output of the comparator, the clamping means being responsive to the control voltage and thus operable adjustably to clamp the output of the comparator means in accordance with the control voltage.

13. A ramp generator means according to claim 12, wherein the clamping means comprises a matched pair of diodes connected between the source of the control voltage and zero voltage.

14. A ramp generator according to claim 13, wherein the diodes are incorporated into an amplifying loop connected between the source of the control voltage and the integrator means.

15. A ramp generator according to claim 14, wherein the amplifying loop comprises a non-inverting amplifier connected in parallel with an inverting amplifier, with the diodes being incorporated into the respective output lines of the amplifiers within feedback loops thereof.

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